CHAPTER 3

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN
FOR THE REMOVAL OF RADIUM AND URANIUM
BY NANOFILTRATION MEMBRANE PROCESSES

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLES

LIST OF ABBREVIATIONS

PSTP	Product-Specific Test Plan
FTO	Field Testing Organization
HF	hollow fiber
HSD	homogeneous solution diffusion model
IMS	Integrated Membrane Systems
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MFI	modified fouling index
mg/L	milligrams per liter
mrem/yr	milli-radiation equivalent man per year
MTC	mass transfer coefficient
MWCO	molecular weight cut-off
NF	nanofiltration
NPDES	National Pollutant Discharge Elimination System
NSF	NSF International
O&M	operation and maintenance
pCi/L	picocuries per liter
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RO	reverse osmosis
rpm	revolutions per minute
RSD	relative standard deviation
SCADA	Supervisory Control and Data Acquisition
SDI	silt density index
SDWA	Safe Drinking Water Act
TFC	thin-film composite
TOC	total organic carbon
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
USGS	United States Geographic Survey
WSWRD	Water Supply and Water Resources Division
WTP	water treatment plant

1.0   APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of nanofiltration (NF) membrane processes to be used within the structure provided by the "EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Radioactive Chemical Contaminants: Requirements For All Studies". This Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing of NF membrane process equipment to achieve removal of dissolved radionuclides, such as radium and uranium. It should also be noted that this Equipment Verification Plan is only applicable to NF or other high-pressure membrane processes.

In order to participate in the equipment verification process for membrane processes, the equipment Manufacturer and their designated Field Testing Organization (FTO) shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol Document as guidelines for the development of a PSTP. The FTO shall clearly specify in its PSTP the radionuclides targeted for removal and sampling program that shall be followed during Verification Testing. The PSTP should generally follow the Verification Testing Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task in the PSTP should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

The primary treatment goal of the equipment employed in this Verification Testing program is to achieve removal of dissolved radionuclides, such as radium and uranium, present in feedwater supplies. The Manufacturer shall establish a Statement of Performance Objectives (Section 3.0 General Approach) that is based upon removal of target radionuclides from feedwaters. The experimental design of the PSTP shall be developed to address the specific Statement of Performance Objectives established by the Manufacturer. Each PSTP shall include all of the included tasks, Tasks 1 to 9.

2.0   INTRODUCTION

Membrane processes are currently in use for a number of water treatment applications ranging from removal of inorganic constituents; total dissolved solids (TDS), total organic carbon (TOC), synthetic organic chemicals (SOCs), radium, uranium, and other constituents.

In order to establish appropriate operations conditions such as permeate flux, recovery, cross-flow velocity, the Manufacturer may be able to apply some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in

preventing the unintentional but unavoidable optimization during the Verification Testing. The need of pre-test optimization should be carefully reviewed with NSF, the FTO and the Manufacturer early in the process.

Pretreatment processes ahead of NF systems are generally required to remove particulate material and to ensure provision of high quality water to the membrane systems. For example, NF membranes cannot generally be applied to treatment of surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, appropriate pretreatment, primarily for removal of particulate and microbiological species, must be applied as specified by the Manufacturer. In the design of the PSTP, the Manufacturer shall stipulate which feedwater pretreatments are appropriate for application upstream of the NF membrane process. The stipulated feedwater pretreatment process(es) shall be employed for upstream of the membrane process at all times during the Equipment Verification Testing Program.

2.1 Radionuclide Removal by Nanofiltration (NF) Membrane Processes

This ETV Testing Plan is applicable to any NF membrane process used to achieve removal of radionuclides. Furthermore, this testing plan is applicable to spiral-wound (SW) and hollow-fiber (HF) membrane configurations.

NF and reverse osmosis (RO) have been shown to be highly effective for the removal of dissolved radionuclides such as radium and uranium. Radium and uranium removal has exceeded 87 and 98 percent, respectively, for diffusion-controlled membranes. However, removal is a function of membrane mass transfer coefficients (MTCs), flux, recovery and feed concentration and will be expected to vary by membrane type. NF and RO are also effective in producing a better overall quality of water.

Some advantages to the use of membrane processes for the removal of radionuclides include:

- a small space requirement;
- removal of contaminant ions, dissolved solids, bacteria, and particles; and
- relative insensitivity to flow and TDS levels, and low effluent concentration.

Disadvantages include:

- higher capital and operating costs;
- higher level of pretreatment required;
- possible membrane fouling; and
- large reject streams.

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications including the removal of radionuclides (e.g. Ra-226, Ra-228, and uranium), natural organic matter (NOM) which contributes to disinfection by-product formation, dissolved minerals, synthetic organic compounds (SOCs) and microbial contaminants such as *Giardia* and *Cryptosporidium*.

Typically, high-pressure membrane applications such as NF membrane processes are capable of removing radionuclides, as well as, ions contributing to hardness. Both radium and uranium are large molecules that have removal rates similar to those of calcium.

In contrast, membrane processes such as microfiltration and/or ultrafiltration (UF/MF) are typically employed to provide a physical barrier for removal of microbial, particulate and suspended contaminants from drinking waters. However, the MF and UF membrane processes have not been shown to be effective for removal of radionuclides and other dissolved substances unless another unit operation such as granular activated or powdered activated carbon is employed.

High and low pressure diffusion controlled membranes are both effective for the rejection of radionuclides. Since NF (low pressure RO) is as effective as RO for radionuclide removal, and can pass more water at lower pressure operations than RO, this test plan pertains to the removal of radium and uranium by NF membrane processes. For RO applications, see the *EPA/NSF ETV Protocol for Equipment Verification Testing for Removal of Inorganic Constituents* Test Plan for Removal of Inorganic Chemical Contaminants by Reverse Osmosis or Nanofiltration.

2.2   Membrane System Design Considerations

Conventional NF membrane systems consist of pretreatment, membrane processing and post-treatment. These processes are discussed in the following sections.

2.2.1   Pretreatment

The purpose of pretreatment is to control and minimize membrane fouling and reduce flux decline. The conventional pretreatment process consists of scale inhibitor (anti-scalant) and/or acid addition in combination with microfiltration. These pretreatment process are used to control scaling and protect the membrane elements; they are required for conventional NF membrane systems. The membranes can be fouled or scaled during operation. Fouling is caused by particulate materials such as colloids and organics that are present in the raw water attaching to the membrane surface, and will reduce the productivity of the membrane. Scaling is caused by the precipitation of a sparingly soluble salt within the membrane because of the solute concentration exceeding solubility. If a raw water is excessively fouling, additional or advanced pretreatment is required.

Flux decline indicated by a reduction in membrane process productivity can be a result of scaling, colloidal fouling, microbiological fouling and organic chemical fouling. Scaling can be approximated by chemical analysis and equilibrium calculations. Fouling indices can approximate colloidal fouling. Microbiological and organic chemical fouling can only be approximated at this time by pilot testing. These mechanisms should be recognized and understood, and are presented below in order to develop strategies to control flux decline.

2.2.1.1   Scaling. In an NF membrane process salts present in the feedwater are concentrated on the feed side of the membrane. This concentration process continues until saturation and a salt precipitation (scaling) occurs. Scaling will reduce membrane productivity, and consequently, will

limit the rate of water that may be recovered as permeate on a sustained basis. The maximum recovery is the recovery at which the limiting salt first begins to precipitate.

Limiting salts can be identified from the solubility products of sparingly soluble salts in the raw feedwater. Since ionic strength increases on the feed side of the membrane, the effect of ionic strength upon the solubility products must also be considered and taken into account for these calculations. Some limiting salts may be controlled via the addition of acid and/or scale inhibitor into the feedwater prior to membrane treatment. Typical sparingly soluble salts that may limit recovery in pressure-driven membrane processes include, but are not limited to: $CaCO_3$; $CaSO_4$; $BaSO_4$; $SrSO_4$; CaF_2; and SiO_2.

2.2.1.2 Colloidal Fouling. Colloidal fouling results from particles that exist in the influent which buildup on the surface of the membrane. The build-up forms a cake, which eventually is compressed, reducing flow through the membrane. Initially, cake formation does not significantly reduce productivity. However, after the cake compresses, the productivity decreases and the compressed cake must be removed. MF/UF membranes can be backwashed to remove the cake. However, NF membranes require chemical cleaning to remove the cake. Advanced pretreatment processes such as cross-flow MF/UF and multi-media filtration should control colloidal fouling.

2.2.1.3 Microbiological Fouling. Microbiological fouling results from biological growth in the membrane element, which results in a reduction in membrane productivity or an increase in pressure drop across an element. No reliable methods have been demonstrated for prediction of biofouling. Microbiological growth can occur in the feed spacers or on the membrane surface. Microbiological growth will occur in membranes, but this growth does not always result in significant productivity loss. Advanced pretreatment processes may aid in controlling microbiological fouling.

2.2.1.4 Chemical Fouling. Chemical fouling results from the interaction of dissolved organic solutes in the feed stream with the membrane surface, which results in a reduction in membrane productivity. Chemical interaction between solute and the membrane surface will occur to some degree, but membrane productivity may not be reduced. Advanced pretreatment processes may aid in the control of chemical fouling.

2.2.2 Advanced Pretreatment

Advanced pretreatment would include unit operations that precede scaling control and static microfiltration. By definition, unit operations that precede conventional pretreatment would be advanced pretreatment. Examples of advanced pretreatment would be coagulation, oxidation followed by greensand filtration, groundwater recharge, continuous cross-flow microfiltration, multi-media filtration, and granular activated carbon (GAC) filtration.

2.2.3 Membrane Processes

The membrane process follows pretreatment. The majority of dissolved contaminants are removed in the membrane process. If the membrane scales or fouls, the productivity of the membrane system

declines and eventually the membranes must be chemically cleaned to restore productivity. Cleaning frequencies for NF systems average about 6 months (Taylor et al. 1990) when treating ground waters and can be as low as 1 to 2 weeks when treating a surface water with integrated membrane systems (IMSs).

MF/UF membranes are sieving controlled and they do not have a low enough molecular weight cut-off (MWCO) range to reject radionuclides. However, NF membranes can achieve significant radionuclide rejection because the MWCO of these membranes are low and most radionuclides cannot pass. This is also the case with inorganic contaminants (IOCs) and SOCs. Radon is a dissolved gas, and like carbon dioxide and hydrogen sulfide, will not be removed by a membrane process. MF/UF membranes do not affect corrosivity because inorganic ions are not removed; however, NF does remove inorganic solutes from water, and this can impact the corrosivity of the permeate water.

2.2.4   Post-Treatment

Typical post-treatment unit operations can consist of disinfection, aeration, stabilization and storage. Aeration may be required to strip dissolved gases (Duranceau 1993). Stabilization may be required to produce a non-corrosive finished water since membrane permeate can be corrosive. Alkalinity recovery is an effective process for recovering dissolved inorganic carbon (DIC) in the permeate. Alkalinity can be recovered by lowering the pH prior to membrane filtration and converting the alkalinity to CO_2, and then raising the pH of the permeate in a closed system to recover dissolved CO_2 as alkalinity. By-passing feedwater and blending it with membrane permeate is another way of stabilizing the finished water; however, blending would negate the benefit of membrane treatment system to act as a barrier against contaminants.

2.2.5   Waste Disposal

In addition to post treatment, the concentrate stream from the membrane processes must be treated and/or disposed of in some manner. Effective concentrate disposal methods depend on the concentrate water quality, local regulations and site-specific factors (AWWARF 1993). The handling and disposal of the wastes generated by treatment technologies removing naturally occurring radionuclides from drinking water pose concerns to the water supplier, to local and State governments and to the public at large. The potential handling hazards associated with radionuclides warrant the development of a viable membrane concentrate disposal method. Information regarding concentrate disposal options can be found in *Suggested Guidelines for the Disposal of Drinking Water Treatment Wastes Containing Naturally Occurring Radionuclides* (USEPA, 1990). The document first addresses the management of radionuclide wastes by first describing the potential sources of these wastes (i.e., water treatment processes). Then there is a brief review of the known information on the radionuclide composition of the associated treatment wastes. The document then describes the plausible disposal alternatives and provides background information from related programs that should assist facilities in selecting a responsible option. The following are disposal options that must be approved by the State or local government prior to implementation of a waste disposal program.

Liquid Waste Disposal

- Direct discharge into storm sewers or surface water.

- Discharge into sanitary sewer.

- Deep well injection.

- Drying or chemical precipitation.

Solid Waste Disposal

- Temporary lagooning (surface impoundment).

- Disposal in landfill.

    a) Disposal without prior treatment.

    b) With prior temporary lagooning.

    c) With prior mechanical dewatering.

- Application to land (soil spreading/conditioning).

- Disposal at State licensed low-level radioactive waste facility.

3.0   GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by an NSF-qualified FTO that is selected by the equipment Manufacturer. Analytical water quality work to be carried out as a part of this Verification Testing Plan will be contracted with a laboratory certified by a State or accredited by a third-party organization (i.e., NSF) or the U.S. Environmental Protection Agency (USEPA) for the appropriate water quality parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Objectives the specific performance criteria to be verified and the specific operational conditions under which the Verification Testing shall be performed. The Statement of Performance Objectives must be specific and verifiable by a statistical analysis of the data. Statements should also be made regarding the applications of the equipment, the known limitations of the equipment and under what conditions the equipment is likely to fail or underperform. There are different types of Statements of Performance Objectives that may be verified in this testing. Two such examples are:

1.   This system is capable of achieving 90 percent removal of radium during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery; temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total dissolved solids concentrations less than 500 mg/L.

2.   This system is capable of producing a product water with a radium concentration less than 5 pCi/L during a 60-day operation period at a flux of 15 gpm/sf (75 percent recovery;

temperature between 20 and 25 °C) in feedwaters with radium concentrations less than 25 pCi/L and total dissolved solids concentrations less than 500 mg/L.

During Verification Testing, the FTO must demonstrate that the equipment is operating at a steady-state prior to collection of data to be used in verification of the Statement of Performance Objectives. For each Statement of Performance Objectives proposed by the FTO and the Manufacturer in the PSTP, the following information shall be provided:

- percent removal of the targeted radionuclides;

- rate of treated water production (i.e., flux);

- recovery;

- feedwater quality regarding pertinent water quality parameters;

- temperature;

- concentration of target radionuclide; and

- other pertinent water quality and operational conditions.

This ETV Testing Plan is broken down into 9 tasks, as shown in the Section 6.0, Overview of Tasks. These Tasks shall be performed by any Manufacturer wanting the performance of their equipment verified by ETV. The Manufacturer's designated FTO shall provide full detail of the procedures to be followed in each Task in the PSTP. The FTO shall specify the operational conditions to be verified during the Verification Testing Plan. All permeate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 77 °F or liters per square meter per hour (L/(m^2-hr) at 25 °C.

4.0   BACKGROUND

This section provides an overview of contaminant removal by NF membrane processes. These items will assist in identifying the radionuclides that can be removed by NF membrane processes, defining NF membrane processes and the mechanisms that will help in qualifying and quantifying the removal efficiency of the NF membrane processes tested.

4.1   Removal Processes

Water supply systems that use sources that contain high radionuclide concentrations will need to implement treatment techniques. Treatment processes that are available for the removal of radium and uranium include, but are not limited to, cation and anion exchange resins, zeolites, adsorptive media, NF or RO membranes, and lime softening.

This Plan discusses the use of NF membrane processes for the removal of dissolved radionuclides. NF is a water treatment technique utilized for the removal of particulate contaminants from water.

Therefore, the following section discusses the removal of Ra-226, Ra-228, and uranium using NF membrane processes.

5.0   DEFINITION OF OPERATIONAL PARAMETERS

The following terms are presented here for subsequent reference in this test plan:

Bulk Rejection - Percent solute concentration retained by the membrane relative to the bulk stream concentration.

$$1 - \frac{C_p}{C_f}$$

where:

C_f = feedwater concentration of specific constituent (mg/L)

C_p = permeate concentration of specific constituent (mg/L)

Bulk Solution - The solution on the high-pressure side of the membrane that has a water quality between that of the influent and concentrate streams.

Cleaning Frequency - The loss or decrease of the mass transfer coefficient (MTC) for water measures membrane productivity over time of production. Membranes foul during operation. Constant production is achieved in membrane plants by increasing pressure. Cleaning is done when the pressure increases by 10 to 15 percent. Cleaning frequency (CF) and a measurement of productivity can be determined from the MTC decline.

$$CF = \frac{\Omega K_w}{\frac{dK_w}{dt}}$$

where:

CF = cleaning frequency (days)

Ω = acceptable rate of MTC loss

dK_w/dt = rate of MTC decline (gsfd/psi-d)

Concentrate (Q_c, C_c) - One of the membrane output streams that has a more concentrated water quality than the feed stream.

Conventional NF/RO Process - A treatment system consisting of acid and/or scale inhibitor addition for scale control, cartridge filtration, NF/RO membrane filtration, aeration, chlorination and corrosion control.

Feed (Q_f, C_f) - Input stream to the membrane process after pretreatment.

Feedwater - Water introduced to the membrane module.

Field Testing Organization (FTO) - An organization qualified to conduct studies and testing of drinking water treatment equipment in accordance with protocols and test plans. The role of the FTO is to complete the application on behalf of the Company; to enter into contracts with NSF, as discussed herein; and arrange for or conduct the skilled operation of a system during the intense periods of testing during the study and the tasks required by the Protocol.

Flux (F_w) - Mass (lb/ft^2-day) or volume (gal/ft^2-day, gsfd, gfd) rate of transfer through membrane surface.

$$F_w = K_w [\Delta P - \Delta \Pi] = \frac{Q_p}{A}$$

where:

F_w = water flux ($M/L^2 \cdot t$)

K_w = global water mass transfer coefficient (t^{-1})

ΔP = transmembranic pressure gradient (M/L^2)

$\Delta \Pi$ = osmotic pressure gradient (M/L^2)

Q_p = permeate flow (L^3/t)

A = membrane surface area (L^2)

Fouling - Reduction of productivity measured by a decrease in the temperature normalized water MTC.

Fouling Indices - Fouling indices are simple measurements that provide an estimate of the required pretreatment for membrane processes. Fouling indices are determined from membrane tests and are similar to mass transfer coefficients for membranes used to produce drinking water. Fouling indices can be quickly developed from simple filtration tests, are used to qualitatively estimate pretreatment requirements and possibly could be used to predict membrane fouling. The silt-density index (SDI), modified fouling index (MFI) and mini plugging factor index (MPFI) are the most common fouling indices.   The SDI, MFI and the MPFI are defined using the basic resistance model, and are quantitatively related to water quality and NF membrane fouling.

Some approximations for required indices prior to conventional membrane treatment are given below (Sung et. al. 1994).

Fouling Index Approximations for NF

Fouling Index	Range
SDI	< 3
MPFI	$< 1.5\,(10^{-4})\ \text{L/s}^2$
MFI	$< 10\ \text{s/L}^2$

Silt-Density Index (SDI): The SDI is the most commonly used test to predict a water's potential to foul a membrane by colloidal particles smaller than 0.45 microns. SDI is only a guide for pretreatment and is not an indication of adequate pretreatment. The SDI is a static measurement of resistance, which is determined by samples taken at the beginning and the end of the test. The SDI test is performed by timing the anaerobic hydraulic flow through a 47 mm diameter, 0.45 micron membrane filter at a constant pressure of 30 psi. The time required for 500 mL of the feedwater to pass through the filter is measured when the test is first initiated, and is also measured at time intervals of 5, 10, and 15 minutes after the start of the test. The value of the SDI is then calculated as follows (ASTM D-4189-82).

$$SDI = \left[\frac{1 - \dfrac{t_i}{t_f}}{t_T} \right] * 100\% \qquad \textbf{(EQUATION 2.4)}$$

where:

t_i = time to collect initial 500 mL sample

t_f = time to collect 500 mL sample at time $t = T$

t_T = total running time of the test; 5, 10, or 15 minutes.

If the index is below a value of 3 then the water should be suitable for NF. If the SDI is below 3, the impact of colloidal fouling is minimized.

Modified Fouling Index (MFI): The MFI is determined using the same equipment and procedure used for the SDI, except that the volume is recorded every 30 seconds over a 15 minute filtration period (Schippers and Verdouw 1980). The development of the MFI is consistent with Darcy's Law in that the thickness of the cake layer formed on the membrane surface is assumed to be directly proportional to the filtrate volume. The total resistance is the sum of the filter and cake resistance. The MFI is defined graphically as the slope of an inverse flow verses cumulative volume curve as shown in the following equations:

$$\frac{dV}{dt} = \frac{\Delta P}{m} \frac{A}{\left(R_f + R_k\right)}$$

$$t = \frac{mVR_f}{\Delta PA} + \frac{mV^2 I}{2\Delta PA^2}$$

$$\frac{1}{Q} = a + MFI * V$$

where:

R_f = resistance of the filter

R_k = resistance of the cake

I = measure of the fouling potential

Q = average flow (liters/second)

a = constant

Typically the cake formation, build-up and compaction or failure can be seen in three distinct regions on a MFI plot. The regions corresponding to blocking filtration and cake filtration represent productive operation, whereas compaction would be indicative of the end of a productive cycle.

Influent - Input stream to the membrane array after the recycle stream has been blended with the feed stream. If there is no concentrate recycle then the feed and influent streams are identical.

Mass Transfer Coefficient (MTC) (K_w) - Mass or volume unit transfer through membrane based on driving force (gfd/psi).

$$K_w = \frac{Q_p}{A\left(\Delta P - \Delta \Pi\right)}$$

where:

K_w = global water mass transfer coefficient (t^{-1})

ΔP = transmembranic pressure gradient (M/L^2)

$\Delta \Pi$ = osmotic pressure gradient (M/L^2)

Q_p = permeate flow (L^3/t)

A = membrane surface area (L^2)

Membrane Element - A single membrane unit containing a bound group of spiral wound or hollow-fiber membranes to provide a nominal surface area for treatment.

Membrane Molecular Weight Cutoff Determination - The membrane molecular weight cutoff (MWCO) of membranes a commonly used to characterize membrane rejection capability.

Membrane MWCO is typically determined by measuring the rejection of different molecular weight nonionic polymers. Solute rejection is defined as:

$$\% \text{ Solute Rejection} = \left(1 - \frac{C_p}{C_f}\right) * 100\%$$

Given the narrow molecular weight bands of polyethylene glycol (PEG) solutions, these nonionic random coil polymers can be applied to membranes for MWCO estimation. Although the percent PEG rejection varies by manufacturer, 80 to 90 percent PEG rejection has been used. Neither the percent rejection nor the material is fixed except by membrane manufacturer. The standard molecular weight solutions can be measured as TOC and correlated to PEG concentration. This correlation can then be applied for assessment of PEG rejection by the membrane and subsequent MWCO determination.

Membrane Productivity - Membrane productivity will be assessed by the rate of mass transfer coefficient (MTC_w) decline over time of operation. As flux declines, a constant product can be achieved by increasing pressure to maintain a constant flux.

Net Driving Pressure (NDP): The net driving pressure (NDP) is calculated using the influent, concentrate and permeate pressure.

$$NDP = \left[\frac{(P_f + P_c)}{2}\right] - P_p - \Delta\Pi$$

where:

NDP = net driving pressure for solvent transport across the membrane (psi, bar)

P_f = feedwater pressure to the feed side of the membrane (psi, bar)

P_c = concentrate pressure on the reject side of the membrane (psi, bar)

P_p = permeate pressure on the treated water side of the membrane (psi, bar)

$\Delta\Pi$ = osmotic pressure (psi)

Osmotic Pressure Gradient ($\Delta\Pi$): The term osmotic pressure gradient refers to the difference in osmotic pressure generated across the membrane barrier as a result of different concentrations of dissolved salts. In order to determine the NDP, the osmotic pressure gradient must be estimated from the influent, concentrate and permeate TDS.

$$\Delta\Pi = \left(\left[\frac{(TDS_f + TDS_c)}{2}\right] - TDS_p\right) * \left(\frac{1 \text{ psi}}{100 \frac{mg}{L}}\right)$$

where:

TDS_f = feedwater total dissolved solids (TDS) concentration (mg/L)

TDS_c = concentrate TDS concentration (mg/L)

TDS_p = permeate TDS concentration (mg/L)

Mass Transfer Coefficient (MTC_w): The MTC_w is calculated by dividing the permeate flow by the membrane surface area.

$$F_w = \frac{Q_p}{A} = MTC_w * NDP$$

From this the MTC_w can be calculated. However, given the relationship between temperature and the viscosity of water, flux should be normalized to a standard temperature condition (25°C). These relationships should be provided by the membrane manufacturer and used to normalize the flux data set as shown below.

$$MTC_{w, 25°C} = \frac{F_{w, 25°C}}{NDP}$$

Temperature Adjustment for Flux Calculation: If manufacture does not specify a temperature correction equation the following equation may be used so that water production can be compared on an equivalent basis.

$$F_{w, 25°C} = F_{w, T°C} * 1.03^{(25°C - T°C)}$$

Recovery: Recovery should also be calculated using the permeate and influent flow.

$$R = \frac{Q_p}{Q_i}$$

Using the above equations the MTC_w, normalized flux and recovery for each stage and the system can be calculated for each set of operational data and plotted as a function of cumulative operating time.

Package Plant - A complete water treatment system including all components from the connection to the raw water(s) intake through discharge to the distribution system.

Permeate (Q_p, C_p) - The membrane output stream that has convected through the membrane.

$$Q_p C_p = Q_f C_f - Q_c C_c$$

Permeate - Water produced by the membrane process.

Permeate Flux - The average permeate flux is the flow of permeate divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where:

J_t = permeate flux at time t (gfd, $L/(h \cdot m^2)$)

Q_p = permeate flow (gpd, L/h)

S = membrane surface area (ft^2, m^2)

It should be noted that only gfd and $L/(h \cdot m^2)$ shall be considered acceptable units of flux for this testing plan.

Pressure Vessel - A single tube or housing that contains several membrane elements in series.

Product-Specific Test Plan (PSTP) - A written document of procedures for on-site/in-line testing, sample collection, preservation, and shipment and other on-site activities described in the EPA/NSF ETV Protocol(s) and Test Plan(s) that apply to a specific make and model of a package plant/modular system.

Raw - Input stream to the membrane process prior to any pretreatment.

Recovery - The recovery of feedwater as permeate water is given as the ratio of permeate flow to feedwater flow:

$$\%\ \text{System Recovery} = \left[\frac{Q_p}{Q_f}\right] * 100\%$$

where:

Q_f = feedwater flow to the membrane (gpm, L/h)

Q_p = permeate flow (gpm, L/h)

Recycle Ratio (r) - The recycle ratio represents the ratio of the total flow of water that is used for cross-flow and the net feedwater flow to the membrane. This ratio provides an idea of the recirculation pumping that is applied to the membrane system to reduce membrane fouling and specific flux decline.

$$\text{Recycle Ratio} = \left[\frac{Q_r}{Q_f}\right]$$

where:

Q_f = feedwater flow to the membrane (gpm, L/h)

Q_r = recycle hydraulic flow in the membrane element (gpm, L/h)

Rejection (mass) – The mass of a specific solute entering a membrane system that does not pass through the membrane.

$$\left(1 - \frac{Q_p C_p}{Q_f C_f}\right)$$

Scaling Control - Controlling precipitation or scaling within the membrane element requires identification of a limiting salt, acid addition for prevention of $CaCO_3$ and/or addition of a scale inhibitor. The limiting salt determines the amount of scale inhibitor or acid addition. A diffusion controlled membrane process will concentrate salts on the feed side of the membrane. If excessive water is passed through the membrane, this concentration process will continue until a salt precipitates and scaling occurs. Scaling will reduce membrane productivity and consequently recovery is limited by the allowable recovery just before the limiting salt precipitates. The limiting salt can be determined from the solubility products of potential limiting salts and the actual feed stream water quality. Ionic strength must also be considered in these calculations as the natural concentration of the feed stream during the membrane process increases the ionic strength, allowable solubility and recovery.

Calcium carbonate scaling is commonly controlled by sulfuric acid addition however sulfate salts are often the limiting salts. Commercially available scale inhibitors can be used to control scaling by complexing the metal ions in the feed stream and preventing precipitation. Equilibrium constants for these scale inhibitors are not available which prevents direct calculation. However some manufacturers provide computer programs for estimating the required scale inhibitor dose for a given recovery, water quality and membrane. The following are general equations for the solubility products and ionic strength approximations.

Solubility Product: Calculation of the solubility product of selected sparingly soluble salts will be important exercise for the test plan in order to determine if there are operational limitations caused by the accumulation of limiting salts at the membrane surface. Text book equilibrium values of the solubility product should be compared with solubility values calculated from the results of experimental Verification Testing, as determined from use of the following equation:

$$K_{sp} = \gamma_A^x \left[A^{y-}\right]^x \gamma_B^y \left[B^{x+}\right]^y$$

where:

K_{sp} = solubility product for the limiting salt being considered

γ = free ion activity coefficient for the ion considered (i.e., A or B)

[A] = molal solution concentration of the anion A for sparingly soluble salt $A_x B_y$

[B] = solution concentration of the anion B

x, y = stiochiometric coefficients for the precipitation reaction of A and B

Mean Activity Coefficient: The mean activity coefficients for each of the salt constituents may be estimated for the concentrated solutions as a function of the ionic strength:

$$\log \gamma_{A,B} = -0.509 \cdot Z_A Z_B \sqrt{\mu}$$

where:

γ = free ion activity coefficient for the ion considered (i.e., A or B)

Z_A = ion charge of anion A

Z_B = ion charge of cation B

μ = ionic strength

Ionic Strength: A simple approximation of the ionic strength can calculated based upon the concentration of the total dissolved solids in the feedwater stream:

$$\mu = (2.5 \cdot 10^{-5}) \cdot (TDS)$$

where:

μ = ionic strength

TDS = total dissolved solids concentration (mg/L)

Solute - The dissolved constituent (mg/L) in a solution or process stream.

Solute Rejection - Solute rejection is controlled by a number of operational variables that must be reported at the time of water sample collection. Bulk rejection of a targeted inorganic chemical contaminant may be calculated by the following equation.

$$\%\ \text{Solute Rejection} = \left[\frac{C_f - C_p}{C_f}\right] * 100\%$$

where:

C_f = feedwater concentration of specific constituent (mg/L)

C_p = permeate concentration of specific constituent (mg/L)

Solvent - A substance, usually a liquid such as water, capable of dissolving other substances.

Solvent and Solute Mass Balance - Calculation of solvent mass balance is performed to verify the reliability of flow measurements through the membrane. Calculation of solute mass balance across the membrane system is performed to estimate the concentration of limiting salts at the membrane surface.

$$Q_f = Q_p + Q_c$$

$$Q_f C_f = Q_p C_p + Q_c C_c$$

where:

Q_f = feedwater flow to the membrane (gpm, L/h)

Q_p = permeate flow (gpm, L/h)

Q_c = concentrate flow (gpm, L/h)

C_f = feedwater concentration of specific constituent (mg/L)

C_p = permeate concentration of specific constituent (mg/L)

C_f = concentrate concentration of specific constituent (mg/L)

Specific Flux - At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure shall be recorded and the specific flux calculated. The efficiency of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficiency achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow an evaluation of irreversible fouling. Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task.

Percent Recovery of Specific Flux: The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux (F_{sf}) and the initial specific flux (F_{si}) measured for the subsequent run.

$$\% \text{ Re cov ery of Specific Flux } = \left[1 - \frac{F_{sf}}{F_{si}}\right] * 100\%$$

where:

F_{sf} = Specific flux (gfd/psi, $L/(h\text{-}m^2)/bar$) at end of run (final)

F_{si} = Specific flux (gfd/psi, $L/(h\text{-}m^2)/bar$) at beginning of run (initial).

Percent Loss of Original Specific Flux: The loss of original specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (F_{si}) divided by the original specific flux (F_{sio}), as measured at the initiation of the first filtration run in a series.

$$\% \text{ Loss of Original Specific Flux } = \left[1 - \frac{F_{si}}{F_{sio}}\right] * 100\%$$

Verification Statement - A written document that summarizes a final report reviewed and approved by NSF on behalf of the USEPA or directly by the USEPA.

Water System - The water system that operates using water treatment equipment to provide potable water to its customers.

6.0   OVERVIEW OF TASKS

This Plan is applicable to the testing of water treatment equipment utilizing NF membrane processes. Testing of NF membrane processes will be conducted by a NSF-qualified Testing Organization that is

selected by the Manufacturer. Water quality analyses will be performed by a state-certified or third party- or EPA- accredited laboratory. This Plan provides objectives, work plans, schedules, and evaluation criteria for the required tasks associated with the equipment testing procedure.

The following is a brief overview of the tasks that shall be included as components of the Verification Testing Program and PSTP for removal of dissolved radionuclides.

- **Task 1: Equipment Verification Testing Plan** – Operate NF membrane processes and associated water treatment equipment for a 60-day testing period to collect data on water quality and equipment performance.

- **Task 2: Characterization of Raw Water** – Obtain chemical, biological and physical characterization of the raw water. Provide a brief description of the watershed that provides the raw water to the water treatment plant.

- **Task 3: Operations and Maintenance (O&M)** - Evaluate an O&M manual for each system submitted. The O&M manual shall characterize NF membrane process design, outline a NF membrane process cleaning procedure or procedures, and provide a concentrate disposal plan.

- **Task 4: Data Collection and Management** – Establish an effective field protocol for data management between the Field Testing Organization and NSF.

- **Task 5: Membrane Productivity** - Demonstrate operational conditions for the membrane equipment; permeate water recovery achieved by the membrane equipment; and rate of flux decline observed over an extended membrane process operation.

- **Task 6: Finished Water Quality** – Evaluate the water quality produced by NF membrane processes as it relates to raw water quality and operational conditions.

- **Task 7: Cleaning Efficiency -** Evaluate the effectiveness of chemical cleaning to the membrane systems.

- **Task 8: Quality Assurance / Quality Control (QA/QC)** – Develop a QA/QC protocol for Verification Testing. This is an important item that will assist in obtaining an accurate measurement of operational and water quality parameters during NF membrane equipment Verification Testing.

- **Task 9: Cost Evaluation** - Develop O&M costs for the submitted NF membrane technology and equipment.

7.0 TESTING PERIODS

The required tasks of the ETV Testing Plan (Tasks 1 through 9) are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. The schedule for equipment monitoring during the 60-day testing period shall be stipulated by the FTO in the PSTP, and shall meet or exceed the minimum monitoring requirements of this testing plan. The FTO shall ensure in the PSTP that sufficient water quality data and operational data will be collected to allow estimation of statistical

uncertainty in the Verification Testing data, as described in the "EPA/NSF ETV Protocol For Equipment Verification Testing For The Removal Of Radioactive Chemical Contaminants: Requirements For All Studies". The FTO shall therefore ensure that sufficient water quality and operational data is collected during Verification Testing for the statistical analysis described herein.

For membrane process treatment equipment, factors that can influence treatment performance include:

- Feedwaters with high seasonal concentrations of inorganic constituents and TDS. These conditions may increase finished water concentrations of inorganic chemical contaminants and may promote precipitation of inorganic materials in the membrane;

- Feedwaters with variable pH; increases in feedwater pH may increase the tendency for precipitation of sparingly soluble salts in the membrane module and may require variable strategies in anti-scalant addition and pH adjustment;

- Cold water, encountered in winter or at high altitude locations;

- High concentrations of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;

- High turbidity, often occurring in spring, as a result of high runoff resulting from heavy rains or snowmelt.

It is highly unlikely that all of the above problems would occur in a water source during a single 60-day period during the Verification Testing Program. Membrane testing conducted beyond the required 60-day testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During the testing periods, evaluation of cleaning efficiency and finished water quality can be performed concurrent with membrane operation testing procedures.

8.0   TASK 1: EQUIPMENT VERIFICATION TEST PLAN

8.1   Introduction

The equipment verification for NF membrane processes for radionuclide removal shall be conducted by a NSF-qualified Field Testing Organization (FTO) that is selected by the Manufacturer. Water quality analytical work to be completed as a part of this ETV Plan shall be contracted with a state-certified or third party- or EPA- accredited laboratory. For information on a listing of NSF-qualified FTOs and state-certified or third party- or EPA- accredited laboratories, contact NSF.

8.2   Objectives

The objective of this task is to operate the equipment provided by a manufacturer, for the conditions and time periods specified by NSF and the manufacturer.

8.3 Work Plan

8.3.1 Equipment Verification Test Plan

Table 8.1 presents the Tasks that are included in this Plan and will be included in the PSTP for radionuclide removal by NF membrane processes. Any Manufacturer wanting to verify the performance of their equipment shall perform these Tasks. The Manufacturer shall provide full detail of the procedures to be followed for each item in the PSTP. The FTO shall specify the operational conditions to be verified during the Verification Testing. All permeate flux values shall be reported in terms of temperature-corrected flux (normalized flux) values, as either gallons per square foot day (gsfd) at $77^{o}F$ or liters per square meter per hour (L/m^2-hr) at $25^{o}C$.

In the design of the PSTP, the FTO shall stipulate which pretreatments are appropriate for application before the selected NF membrane processes. The recommended pretreatment process(es) shall then be employed by the Manufacturer for raw water pretreatment during implementation of the Equipment Verification Testing Program.

TABLE 8.1: Task Descriptions

No.	Task	Description
1	Test Plan	Water treatment equipment shall be operated for a minimum of 60 days per test period to collect data on water quality and equipment performance.
2	Characterization of Raw Water	Obtain chemical, biological and physical characterization of the raw water.
3	O&M Manual	Evaluate O&M manual for process.
4	Data and Collection Management	Develop data protocol between FTO and NSF.
5	Membrane Productivity	Demonstrate conditions for membrane equipment, permeate water recovery, observe rate of flux decline
6	Finished Water Quality	Evaluate the water quality produced by NF membrane processes as it relates to raw water quality and operational conditions.
7	Cleaning Efficiency	Evaluate effectiveness of chemical cleaning and confirm cleaning procedures restore membrane productivity.
8	QA/QC	Enforce QA/QC standards.
9	Cost Evaluation	Provide O&M costs of system.

8.3.2 Routine Equipment Operation

During the time intervals between equipment verification runs, the water treatment equipment may be used for production of potable water. If the equipment is being used for the production of potable water, routine operation for water production is expected. The operating and water quality

data collected and furnished to the local regulatory agency should also be supplied to the NSF-qualified FTO.

8.4   Analytical Schedule

The entire equipment verification shall be performed over a 60-day period (not including time for system shakedown and mobilization). At a minimum, one, 60-day period of Verification Testing shall be conducted in order to provide equipment testing information for NF membrane process performance. A full one-year testing period would also be acceptable, but is not required.

The required tasks for the equipment verification are designed to be completed over a 60-day period, not including mobilization, shakedown and start-up. NF membrane process testing conducted beyond the required 60-day testing may be used for fine-tuning of NF performance or for evaluation of additional operational conditions. During the 60-day testing period, evaluation of finished water quality can be performed concurrent with the percent removal testing procedures.

8.5   Evaluation Criteria

The equipment testing period will include a Verification Test of at least 60-days. .

9.0   TASK 2: CHARACTERIZATION OF RAW WATER

9.1   Introduction

A characterization of raw water quality is needed to determine if the concentrations of Ra-226, Ra-228, uranium, or other raw water contaminants are appropriate for the use of NF membrane processes. The feedwater quality can influence the performance of the equipment.

9.2   Objectives

One reason for performing a raw water characterization is to obtain at least one-year of historical raw water quality data from the raw water source. The objective is to:

- demonstrate seasonal effects on the concentration of radionuclides; and
- develop maximum and minimum concentrations for the contaminant.

If historical raw water quality is not available, a raw water quality analysis of the proposed feedwater shall be performed prior to equipment Verification Testing.

9.3   Work Plan

The characterization of raw water quality is best accomplished through the performance of laboratory testing and the review of historical records. Sources for historical records may include municipalities, laboratories, USGS (United States Geographical Survey), USEPA, and local regulatory agencies. If historical records are not available preliminary raw water quality testing shall be performed prior to

equipment Verification Testing. The specific parameters of characterization will depend on the NF membrane process that is being tested. The following characteristics should be reviewed and documented:

- Radium-226
- Radium-228
- Uranium
- Temperature
- pH
- TDS/Conductivity
- Total Hardness
- Calcium Hardness
- Total Organic Carbon

- Total Alkalinity
- Turbidity
- True Color
- Chloride
- Fluoride
- Sulfate
- Ammonia
- Iron
- Manganese

- Silica
- Barium
- Nitrate
- Sodium
- Potassium
- Strontium
- Phosphate
- SDI
- MFI

Data collected should reflect seasonal variations in the above data if applicable. This will determine variations in water quality parameters that will occur during Verification Testing. The data that is collected will be shared with NSF so that the FTO can determine the significance of the data for use in developing a test plan. If the raw water source is not characterized, the testing program may fail, or results of a testing program may not be considered acceptable. A description of the raw water source should also be included with the feedwater characterization. The description may include items such as:

- size of watershed;
- topography;
- land use;
- nature of the water source; and
- potential sources of pollution.

9.4   Schedule

The schedule for compilation of adequate water quality data will be determined by the availability and accessibility of historical data. The historical water quality data can be used to determine the suitability of NF membrane processes for the treatment for the raw source water. If raw water quality data is not available, a preliminary raw water quality testing should be performed prior to the Verification Testing of the NF membrane equipment.

9.5   Evaluation Criteria

The feedwater quality shall be evaluated in the context of the Manufacturer's Statement of Performance Objectives for the removal of radionuclides. The feedwater should challenge the capabilities of the

chosen equipment, but should not be beyond the range of water quality suitable for treatment by the chosen equipment. For NF membrane processes, a complete scan of water quality parameters may be required in order to determine limiting salt concentrations, necessary for establishing pretreatment criteria.

10.0   TASK 3: OPERATIONS AND MAINTENANCE MANUAL

An operations and maintenance (O&M) manual for NF membrane processes to be tested for radionuclide removal shall be included in the Verification Testing evaluation.

10.1   Objectives

The objective of this task is to provide an O&M manual that will assist in operating, troubleshooting and maintaining NF membrane process performance. The O&M manual shall:

- characterize NF membrane process design;
- outline a NF membrane process cleaning procedure or procedures; and
- provide a concentrate disposal plan.

The concentrate disposal plan must be approved by the appropriate regulatory authority for the verification period before verification testing begins. A fully developed concentrate disposal plan would be required because of the radionuclides that have been concentrated in the waste stream. Criteria for evaluation of the equipment's O&M Manual shall be compiled and then evaluated and commented upon during verification by the FTO. An example is provided in Table 10.1.

The purpose of O&M information is to allow utilities to effectively choose a technology that their operators are capable of operating, and provide information on how many hours the operators can be expected to work on the system. Information about obtaining replacement parts and ease of operation of the system would also be valuable.

10.2   O&M Work Plan

Descriptions for pretreatment, NF membrane process, and post-treatment to characterize the NF membrane system unit process design shall be developed. Membrane processes shall include the design criteria and NF membrane element characteristics. Examples of information required relative to the membrane design criteria and element characteristics are presented in Tables 10.2 and 10.3, respectively.

The NF membrane treatment process will be optimized for sustained production under high product water recovery and solvent flux. Productivity goals shall include cleaning frequencies greater than 6 months for no more than 15 percent productivity decline. However, it should be noted that some systems may accommodate a 20 percent MTC or flux decline. Therefore, cleaning frequency could be predicted using the equation for cleaning frequency.

Productivity decline will be indicate and signal by either normalized flux decline or normalized solvent mass transfer (MTC_w) reduction. Normalized means that the flux has been adjusted for temperature and pressure. Conditions of constant system pressure where solvent flux remains greater than 90 percent of its original value would be desired. The use of the normalized MTC_w for productivity decline would eliminate the need for constant system pressure for productivity decline determination. Should constant flux be used as an operating guideline for particles under application, a 10 to 15 percent pressure increase would constitute criteria for cleaning.

Chemical cleaning of the membranes will be performed as necessary for the removal of reversible foulants per manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solutions could also be analyzed for determining which constituents may have adsorbed or precipitated onto the membrane surface. Analysis of cleaning solutions can be coupled with mass balances on the same solutes monitored during operation to determine solute accrual in nanofilters. This may prove useful for establishing the mechanism of removal for some radionuclides. A cleaning efficiency evaluation is described in Section 5.0.

TABLE 10.1: OPERATIONS & MAINTENANCE MANUAL CRITERIA -
NF Membrane Process Equipment

MAINTENANCE:

The manufacturer should provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- flow meters
- pressure gauges
- pumps
- motors
- valves
- chemical feeders
- mixers

The manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- membranes
- pressure vessels
- piping

OPERATION:

The manufacturer should provide readily understood recommendation for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:

Chemical feeders:

- calibration check
- settings and adjustments - how they should be made
- dilution of chemicals and scale inhibitors - proper procedures

Monitoring and observing operation:

- mass balance calculations
- recovery calculation

OPERATION (continued):

Monitoring and observing operation (continued):

- pressure losses

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- flux decline;

- no raw water (feedwater) flow to plant;

- when the water flow rate through the equipment can not be controlled;

- no chemical feed;

- automatic operation (if provided) not functioning;

- no electric power; and

- sand or silt entrainment.

The following are recommendations regarding operability aspects of membrane processes. These aspects of plant operation should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program. During Verification Testing, attention shall be given to equipment operability aspects.

- are chemical feed pumps calibrated?

- are flow meters present and have they been calibrated?

- are pressure gauges calibrated?

- are pH meters calibrated?

- are TDS or conductivity meters calibrated?

- can cleaning be done automatically?

- can membrane seals be easily replaced?

- does remote notification occur (alarm) when pressure increases > 15% or flow drops > 15%?

The reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Operating Conditions and Treatment Equipment Performance, in the Membrane Process Test Plan.

TABLE 10.2: NF Membrane Plant Design Criteria Reporting Items

Parameter	Value
Number of stages	
Number of pressure vessels in stage 1	
Number of pressure vessels in stage 2	
Number of elements per pressure vessel	
Recovery per stage (%)	
Recovery for system (%)	
Design flow (gpm)	
Design temperature (°C)	
Design flux (gsfd)	
Surface area per element (ft^2)	
MTC$_W$ (gsfd/psi)	
Maximum flow rate to an element (gpm)	
Minimum flow rate to an element (gpm)	
Pressure loss per element (psi)	
Pressure loss in stage entrance and exit (psi)	
Feed stream TDS (mg/L)	
Ra-226 rejection (%)	
Ra-228 rejection (%)	
Uranium rejection (%)	

TABLE 10.3: NF Membrane Element Characteristics

Membrane manufacturer			
Membrane module model number			
Size of element used in study (e.g. 4" x 40")			
Active membrane area of element used in study			
Active membrane area of an equivalent 8" x 40" element			
Purchase price for an equivalent 8" x 40" element ($)			
Molecular weight cutoff (Daltons)			
Membrane material / construction			
Membrane hydrophobicity (circle one)	Hydrophilic		Hydrophobic
Membrane charge (circle one)	Negative	Neutral	Positive
Design pressure (psi)			
Design flux at the design pressure (gfd)			
Variability of design flux (%)			
MTC_W (gfd/psi)			
Standard testing recovery (%)			
Standard testing pH			
Standard testing temperature (°C)			
Design cross-flow velocity (fps)			
Maximum flow rate to the element (gpm)			
Minimum flow rate to the element (gpm)			
Required feed flow to permeate flow rate ratio			
Maximum element recovery (%)			
Rejection of reference solute and conditions of test (e.g. solute type and concentration)			
Variability of rejection of reference solute (%)			
Spacer thickness (ft)			
Scroll width (ft)			
Acceptable range of operating pressures			
Acceptable range of operating pH values			
Typical pressure drop across a single element			
Maximum permissible SDI			
Maximum permissible turbidity (NTU)			
Chlorine/oxidant tolerance			
Suggested cleaning procedures			

Note: Some of this information may not be available, but this table should be filled out as completely as possible for each membrane tested.

11.0   TASK 4: DATA COLLECTION AND MANAGEMENT

11.1   Introduction

The data management system used in the Verification Testing Program shall involve the use of computer spreadsheets, in addition to manual recording of operational parameters for the NF membrane processes on a daily basis.

11.2   Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data to NSF for verification purposes. Chain-of-Custody protocols will be developed and adhered to.

11.3   Work Plan

11.3.1   Operation Data Collection and Documentation

The following protocol has been developed for data handling and data verification by the FTO. In addition to daily operational data sheets, a Supervisory Control and Data Acquisition (SCADA) system could be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into electronic spreadsheets. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of NF membrane process operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

Field testing operators shall record data and calculations by hand in laboratory notebooks for a minimum of three times per day. (Daily measurements shall be recorded on specially prepared data log sheets as appropriate. Figure 12.2 presents an example of a daily log sheet). The laboratory notebook shall provide copies of each page. The original notebooks shall be stored on-site; the copied sheets shall be forwarded to the project engineer of the FTO at least once per week during the 60-day testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include:

- descriptions of the equipment and test runs;
- names of visitors; and
- descriptions of any problems or issues.

Such descriptions shall be provided in addition to experimental calculations and other items.

11.3.2   Data Management

The database for the project shall be set up in the form of custom designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the field laboratory analysis notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time.

Following data entry, the spreadsheet shall be printed and the printout shall be checked against the handwritten data sheet. Any corrections shall be noted on the hardcopies and corrected on the screen, and then the corrected recorded calculations will also be checked and confirmed. The field testing operator or engineer performing the data entry or verification step shall initial each step of the verification process.

Each experiment (e.g. each NF membrane process test run) shall be assigned a run number, which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA- accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the FTO. This data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

11.3.3   Statistical Analysis

For the analytical data obtained during Verification Testing, 95 percent confidence intervals shall be calculated by the FTO for selected water quality parameters. The specific Plans shall specify which water quality parameters shall be subjected to the requirements of confidence interval calculation. As the name implies, a confidence interval describes a population range in which any individual population measurement may exist with a specified percent confidence. When presenting the data, maximum, minimum, average and standard deviation should be included.

Calculation of confidence intervals shall not be required for equipment performance obtained during the equipment Verification Testing Program. In order to provide sufficient analytical data for statistical analysis, the FTO shall collect three discrete water samples at one set of operational conditions for each of the specified water quality parameters during a designated testing period.

12.0   TASK 5: MEMBRANE PRODUCTIVITY

12.1   Introduction

The removal of Ra-226, Ra-228, and uranium from drinking water supplies is accomplished by NF membrane filtration. The effectiveness of NF membrane processes for radionuclide removal will be evaluated in this task. Membrane mass transfer coefficient, flux and recovery will be evaluated in this task. After installation of the NF process, the membranes tend to have characteristic flux decline with

time until the membrane stabilizes. After this initial flux decline, the rate of flux decline will be used to demonstrate membrane performance for the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the Manufacturer in terms of a temperature-corrected flux (normalized flux) value (e.g., gsfd at 77 °F or L/(m²hr) at 25 °C) before the initiation of the Program.

Flux decline is a function of water quality, membrane type, configuration and operational conditions. In establishing the range of operation for the membrane performance evaluations, limiting salt information should be used to define the run scenarios. The run conditions should include operating scenarios, which approach and exceed these projected limits. Subsequent water quality analysis will allow for assessment of the degree of saturation of the sparingly soluble salts in the final concentrate. The degree of saturation of the salts should then be compared to resulting membrane productivity decline. Table 12.1 presents an example of membrane pretreatment data required to provide baseline conditions and assist in evaluating membrane productivity.

Some Manufacturers may wish to employ the NF membrane process with a pretreatment process in order to reduce flux decline and improve removal of radionuclides. Any pretreatment included in the membrane treatment system that is designed for removal of radionuclides shall be considered an integral part of the NF membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes.

12.2   Experimental Objectives

The objectives of this task are to demonstrate:

- Operational conditions for the membrane equipment;
- Permeate water recovery achieved by the membrane equipment; and
- Rate of flux decline observed over an extended membrane process operation.

Raw water quality shall be measured prior to system operation and then monitored every two weeks during the 60-day testing period at a minimum. It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the Manufacturer, as it pertains to permeate flux, transmembrane pressure, and radium and uranium removal.

12.3   Work Plan

Determination of ideal membrane operating conditions for a particular water may require as long as one year of operation. For this task the Manufacturer shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the membrane treatment system. The Manufacturer shall evaluate flux decline. The Manufacturer shall also determine the limiting salt and identify possible foulants and scalants and use this for performance evaluation for their particular membrane equipment. The set of operating conditions shall be maintained

for the 60-day testing period (24-hour continuous operation). The Manufacturer shall specify the primary permeate flux at which the equipment is to be verified. Additional operating conditions can be verified in separate 60-day testing periods.

After set-up and "shakedown" of membrane equipment, membrane operation should be established at the flux condition to be verified. Testing of additional operational conditions could be performed by extending the number of 60-day testing periods beyond the initial 60-day test period required by the Verification Testing Program at the discretion of the Manufacturer and their designated FTO.

Additional 60-day periods of testing may also be included in the Verification Testing Plan in order to demonstrate membrane performance under different feedwater quality conditions. For membrane processes, extremes of feedwater quality (e.g., low temperature, high TOC concentration, high turbidity, high SDI) are the conditions under which membranes are most prone to fouling and subsequent failure. At a minimum the performance of the NF membrane equipment relative to radionuclide removal shall be documented during those periods of variable feedwater conditions. The Manufacturer shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional 60-day testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with finished water quality and if applicable, cleaning efficiency. With the exception of additional testing periods conducted at the Manufacturer's discretion, no additional membrane test runs are required for performance of cleaning efficiency and finished water quality. A continuous yearlong evaluation, although not required, may be of benefit to the Manufacturer for verification of long term trends.

12.3.1 Operational Data Collection

Measurement of membrane feedwater flow and permeate flow (recycle flow where applicable) and system pressures shall be collected at a minimum of three times per day. Table 12.2 is an example of a daily operational data sheet for a two-stage membrane system. This table is presented for informational purposes only. The actual forms will be submitted as part of the test plan and may be site-specific. Measurement of feedwater temperature to the membrane shall be made along with these three daily measurements in order to provide data for normalizing flux with respect to temperature.

Water quality should be analyzed from the same locations identified for TDS in Table 12.2 prior to start-up and then every two weeks for the parameters identified in Table 12.3, except for each radionuclide, which will be monitored weekly. Power usage for operation of the membrane equipment (pumping requirements, power factor, etc.) shall also be closely monitored and recorded by the FTO during the 60-day testing period. In addition, measurement of power consumption and chemical consumption shall be quantified by recording such items as day tank concentration, daily volume consumption and unit cost of chemicals.

12.3.2   Feedwater Quality Limitations

The characteristics of feedwater used during the 60-day testing period (and any additional 60-day testing periods) shall be explicitly stated in reporting the membrane flux and recovery data for each period. Accurate reporting of such feedwater characteristics is critical for the Verification Testing Program, as these parameters can substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions. The following criteria and trends should also be presented in the Verification Testing Program:

- Evaluation criteria and minimum reporting requirements.
- Plot graph of specific radionuclide removals over time for each 60-day test period.
- Plot graph of NDP over time for each 60-day test period.
- Plot graph of TDS over time for each 60-day test period.
- Plot graph of specific flux normalized to 25°C over time for each 60-day test period.
- Plot graph of MTC_w over time for each 60-day test period.
- Plot graph of recovery over time for each 60-day test period.

TABLE 12.1: NF Membrane Pretreatment Data

Foulants and Fouling Indices of the Feedwater Prior to Pretreatment	
Alkalinity (mg/L of $CaCO_3$)	
Ca Hardness (mg/L of $CaCO_3$)	
LSI	
Dissolved iron (mg/L)	
Total iron (mg/L)	
Dissolved aluminum (mg/L)	
Total aluminum (mg/L)	
Fluoride (mg/L)	
Phosphate (mg/L)	
Sulfate (mg/L)	
Calcium (mg/L)	
Barium (mg/L)	
Strontium (mg/L)	
Reactive silica (mg/L as SiO_2)	
Turbidity (NTU)	
SDI	
Pretreatment Processes Used Prior to Nanofiltration	
Pre-filter listed pore size (µm)	
Type of acid used	
Acid concentration (units)	
mL of acid per L of feed	
Type of scale inhibitor used	
Scale inhibitor concentration (units)	
mL of scale inhibitor per L of feed	
Type of coagulant used	
Coagulant dose (mg/L)	
Type of polymer used during coagulation.	
Polymer dose (mg/L)	

TABLE 12.2: Daily Operations Log Sheet for a Two-Stage Membrane System

Date:

Parameter	Measurement 1	Measurement 2	Measurement 3
Time			
Initial			
Feed			
Q_{feed} (gpm)			
TDS_{feed} (before pretreatment) (mg/L)			
TDS_{feed} (after pretreatment) (mg/L)			
P_{feed} (psi)			
pH_{feed} (before pretreatment)			
pH_{feed} (after pretreatment)			
T_{feed} (°C)			
Permeate - Stage 1			
Q_{p-S1} (gpm)			
TDS_{p-S1} (mg/L)			
P_{p-S1} (psi)			
Concentrate - Stage 1			
Q_{c-S1} (gpm)			
TDS_{c-S1} (mg/L)			
P_{c-S1} (psi)			
T_{c-S1} (°C)			
Permeate - Stage 2			
Q_{p-S2} (gpm)			
TDS_{p-S2} (mg/L)			
P_{p-S2} (psi)			
Concentrate - Stage 2			
Q_{c-S2} (gpm)			
TDS_{c-S2} (mg/L)			
P_{c-S2} (psi)			
Finished			
Q_{fin} (gpm)			
TDS_{fin} (mg/L)			
Recovery (Q_{fin}/Q_{feed}) (%)			
Recycle			
$Q_{recycle}$ (gpm)			

TABLE 12.3: Operating and Water Quality Data Requirements for Membrane Processes

Parameter	Frequency for Sampling
Feedwater Flow	3 / Daily
Permeate Water Flow	3 / Daily
Concentrate Water Flow	3 / Daily
Feedwater Pressure	3 / Daily
Permeate Water Pressure	3 / Daily
Concentrate Water Pressure	3 / Daily
List Each Chemical Used, And Dosage	Daily Data Or Monthly Average
Hours Operated Per Day	Daily
Hours Operator Present Per Day	Monthly Average
Power Consumption (kWh/Million Gallons)	Monthly
Independent check on rates of flow	Weekly
Independent check on pressure gages	Weekly
Verification of chemical dosages	Monthly
Feedwater and Finished Water Characteristics	
Radium-226	Weekly
Radium-228	Weekly
Uranium	Weekly
Gross Alpha and Beta Emitters	Weekly
Temperature	3 / Daily
pH	3 / Daily
TDS/Conductivity	3 / Daily
Turbidity	Every two weeks
True Color	Every two weeks
Total Organic Carbon	Every two weeks
UV Absorbance (254 nm)	Every two weeks
Total Alkalinity	Every two weeks
Total Hardness	Every two weeks
Calcium Hardness	Every two weeks
Sodium	Every two weeks
Chloride	Every two weeks
Iron	Every two weeks
Manganese	Every two weeks
Sulfate	Every two weeks
Fluoride	Every two weeks
Silica	Every two weeks
Ammonia	Every two weeks
Potassium	Every two weeks
Strontium	Every two weeks
Barium	Every two weeks
Nitrate	Every two weeks
TTHM (optional)	Every two weeks
THAA (optional)	Every two weeks
TOX (optional)	Every two weeks

13.0   TASK 6: FINISHED WATER QUALITY

13.1   Introduction

Water quality data shall be collected for the raw and finished water as provided previously in Table 12.3. (Note, in some instances sampling concentrate water quality may be required because detection limits may be too low for a specified parameter.) At a minimum, the required sampling shall be one sampling at start-up and two sampling events per month while raw water samples are collected. Water quality goals and target removal goals for the NF membrane equipment should be proven and reported in the PSTP.

13.2   Objectives

The objective of this task is to verify the Manufacturer's objectives. A list of the minimum number of water quality parameters to be monitored during equipment Verification Testing has been provided in this document. The actual water quality parameters selected for testing and monitoring shall be stipulated in the PSTP.

13.3   Work Plan

The PSTP shall identify the treated water quality objectives to be achieved in the Statement of Performance Objectives of the equipment to be evaluated in the Verification Testing Program. The PSTP shall also identify in the Statement of Performance Objectives the radionuclide that shall be monitored during equipment testing. The Statement of Performance Objectives prepared by the PSTP shall indicate the range of water qualities and operating conditions under which the equipment can be challenged while successfully treating the contaminated water supply.

It should be noted that many of the drinking water treatment systems participating in the NF Membrane Process Verification Testing Program will be capable of achieving multiple water treatment objectives. Although this NF Membrane Process Plan is oriented towards removal of Ra-226, Ra-228, and uranium, the Manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified FTO. A state-certified or third party- or EPA- accredited laboratory shall perform analysis of the remaining water quality parameters. Representative methods to be used for measurement of water quality parameters in the field and lab are identified in Table 13.1. The analytical methods utilized in this study for on-site monitoring of raw and finished water qualities are described in Quality Assurance/ Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and USEPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

TABLE 13.1: Water Quality Analytical Methods

Parameter	AWWA Method [1]	EPA Method [2]
Radium-226	7500-Ra	903.1
Radium-228	7500-Ra	---
Uranium	7500-U	908.0
Gross Alpha and Beta Emitters	7110	900.0
Temperature	2550	170.1
pH	$4500\text{-}H^+$	150.2
TDS/Conductivity	2510	120.1
Turbidity	2130	180.1
True Color	2120	110.2
Total Organic Carbon	5310	415.2
UV Absorbance (254 nm)	5910	---
Total Alkalinity	2320	310.2
Total Hardness	2340	130.2
Calcium Hardness	3500-Ca	215.2
Sodium	3500-Na	273.1
Chloride	$4500\text{-}Cl^-$	325.1
Iron	3500-Fe	236.1
Manganese	3500-Mn	243.1
Sulfate	$4500\text{-}SO_4^{-2}$	375.4
Fluoride	$4500\text{-}F^-$	340.1
Silica	$4500\text{-}SiO_2$	370.1
Ammonia	$4500\text{-}NH_3$	350.2
Potassium	3500-K	256.1
Strontium	3500-Sr	200.7
Barium	3500-Ba	208.1
Nitrate	$4500\text{-}NO_3^-$	352.1
TTHM	5710	551
THAA	5710	552
TOX	5320	1648

1. AWWA, Standard Methods for the Examination of Water and Wastewater, 20th Edition, 1999.

2. EPA, Methods and Guidance for Analysis of Water, EPA 821-C-97-001, April 1997.

For the water quality parameters requiring analysis at an off-site laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the state-certified or third party- or EPA- accredited laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, including chain-of custody requirements, as specified by the analytical lab.

13.4   Analytical Schedule

13.4.1   Removal of Radioactive Chemical Contaminants

During the steady-state operation of each membrane testing period, radionuclide mass balances shall be performed on the membrane feed, permeate and concentrate water in order to determine the radionuclide removal capabilities of the membrane system.

13.4.2   Feed and Permeate Water Characterization

At the beginning of each membrane testing period, the raw water, permeate and in some cases the concentrate water shall be characterized at a single set of operating conditions by measurement of the water quality parameters identified in Table 12.3.

13.4.3   Water Quality Sample Collection

Water quality data shall be collected at established intervals during each period of membrane equipment testing. The minimum monitoring frequency for the required water quality parameters is once at start-up and weekly for radionuclides and every two weeks for the remaining water quality parameters. The water quality sampling program may be expanded to include a greater number of water quality parameters and to require a greater frequency of parameter sampling. Analyses for organic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, in order to provide the maximum degree of comparability between water quality analytes.

No monitoring of microbial populations shall be required in this Equipment Verification Testing Plan. However, the Manufacturer may include optional monitoring of indigenous microbial populations to demonstrate removal capabilities.

13.4.4   Raw Water Quality Limitations

The characteristics of feedwater encountered during each 60-day testing period shall be explicitly stated. Accurate reporting of such raw water characteristics such as those identified in Table 12.3 are critical for the Verification Testing Program, as these parameters can substantially influence membrane performance.

13.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal or reduction of radionuclides.

- Water quality and removal goals specified by the Manufacturer.

14.0 TASK 7: CLEANING EFFICIENCY

14.1 Introduction

There are certain types of foulant scales that pose an immediate threat to the operational integrity of a membrane process. Examples of scale include calcium carbonate scale and silica or sulfate scale. The following guidelines can be used with the normalized performance data to determine the maximum fouling to allow prior to cleaning the system:

a. 10-15 percent decrease in the normalized permeate flow rate

b. 10-15 percent increase in the normalized system differential pressure

c. Decrease in the salt rejection for a constant feedwater salinity

Should scaling or fouling occur during or following the test runs, the membrane equipment shall require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the fouling frequency of the membrane during each specified test period. In the case where the membrane does not fully reach the operational criteria for fouling as specified by the Manufacturer, chemical cleaning shall be performed after the 30 days of operation, with a record made of the operational conditions before and after cleaning.

The membrane treatment process will be optimized for sustained production under high product water recovery and solvent flux. Productivity goals should include cleaning frequencies once every 6 months for no more than 10 percent productivity decline for groundwater sources. Productivity goals should include cleaning frequencies once per month for no more than 10 percent productivity decline for surface water sources, if applicable.

Either normalized flux decline or solvent mass transfer (MTC_w) reduction will determine productivity decline. Therefore, conditions of constant system pressure where solvent flux remains greater than 90 percent of its original value would be desired. For a constant flux system, a 10 percent increase in pressure would serve as a basis for cleaning. The use of the normalized MTC_w for productivity decline would eliminate the need for constant system pressure for productivity decline determination. Chemical cleaning of the membranes will be performed as necessary for the removal of reversible foulants per Manufacturer specifications. These cleaning events are to be documented and used as an aid in determining the nature of the fouling or scaling conditions experienced by the system. The cleaning solution backwash should also be analyzed to determine which constituents might have been removed from the membrane surface during cleaning.

14.2   Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning to the membrane systems. The intent of this task is to confirm that standard Manufacturer recommended cleaning practices are sufficient to restore membrane productivity for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the Manufacturer recommendations. This task is considered a "proof of concept" effort, not an optimization effort.

14.3   Work Plan

The membrane systems may become fouled during the membrane test runs. These fouled membranes shall be utilized for the cleaning assessments herein. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer and vary according to identified foulants or scale. After each chemical cleaning of the membranes, the system shall be restarted and then returned to the operating condition being tested.

The Manufacturer and their designated FTO shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the FTO shall collect the information during verification testing for inclusion in the verification report:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- duration of each cleaning step
- chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed

14.4   Recommended Disposal Procedures

Methods of disposal of membrane concentrate include, but are not limited to the following:

- Wastewater treatment plant;
- Spray irrigation;
- Deep well injection; or
- Discharge to a surface water through the National Pollutant Discharge Elimination System (NPDES).

However radionuclides are considered a potentially hazardous waste and the effluent must be monitored since it is concentrated. The concentrate disposal may require other State and/or Federal permits. In addition, a description of all cleaning equipment and anticipated cleaning chemical waste streams and their operations shall be described and included in the O&M manual.

14.5   Analytical Schedule

14.5.1   Sampling

The radionuclide concentration of the backwash shall be measured to determine which constituents might have been removed from the membrane surface during cleaning. The purpose of this is to evaluate potential membrane backwash disposal issues associated with the cleaning. Conductivity, pH, and turbidity should also be recorded to monitor flush periods.

14.5.2   Operational Data Collection

Flow and pressure data shall be collected before system shutdown due to membrane fouling; flow and pressure data shall also be collected after chemical cleaning.

15.0   TASK 8: QUALITY ASSURANCE/QUALITY CONTROL

15.1   Introduction

Quality assurance and quality control (QA/QC) of the operation of the NF membrane process equipment and the measured water quality parameters shall be maintained during the Equipment Verification Testing Program.

15.2   Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

15.3   QA/QC Work Plan

Equipment flow rates and associated transmitter signals should be calibrated and verified on a routine basis. A routine daily walk through during testing shall be established to check that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to verify that chemicals are being fed at the defined flow rate, and into a flow stream that is operating at the expected flow rate. This will provide correct chemical concentrations in the flow stream. In-line monitoring equipment such as flow meters, etc. shall be checked monthly to verify that the readout matches with the actual measurement (i.e. flow rate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

When collecting water quantity data, all system flow meters will be calibrated using the classic bucket and stopwatch method where appropriate. Hydraulic data collection will include the measurement of the finished water flow rate by the "bucket test" method. This would consist of filling a calibrated vessel

to a known volume and measuring the time to fill the vessel with a stopwatch. This will allow for a direct check of the system flow measuring devices.

Mass balances will be performed on the system for water quality parameters measured in the feed, permeate and concentrate streams. This will enable an additional quality control check on the accuracy and reliability of the analyzed data. Radionuclides in particular will be analyzed in each process stream. However, the difficulty in measuring low level radionuclides may limit the mass balance to be calculated based on feed and concentrate. Mass balances may provide insight into the mechanism for rejection of individual radionuclides. For example, mass balances showing incomplete recovery for a particular radionuclide may suggest possible adsorption onto the membrane surface.

15.3.1   Daily QA/QC Verification

- Chemical feed pump flow rates (check and verify components)
- On-line conductivity meters (check and verify components)
- On-line pH meters (check and verify components)

15.3.2   Monthly QA/QC Verification

- Chemical feed pump flow rates (verify volumetrically over a specific time period)
- On-line conductivity meters (recalibrate)
- On-line flow meters/rotometers (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)

15.4   Analytical Methods

Use of either bench-top field analytical equipment or on-line equipment will be acceptable for the Verification Testing; however, on-line equipment is recommended for ease of operation. Use of on-line equipment is preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. However, standard and uniform calibration and standardization techniques that are approved should be employed. Table 13.1 lists American Water Works Association (AWWA) and EPA standard methods of analysis.

16.0   TASK 9: COST EVALUATION

This Plan includes the assessment of costs of verification with the benefits of testing NF membrane processes over a wide range of operating conditions. Therefore, this Plan requires that one set of operating conditions be tested over a 60-day testing period. The equipment Verification Tests will provide information relative to systems, which provide desired results and the cost, associated with the

systems. Design parameters are summarized in Table 16.1. These parameters will be used with the equipment Verification Test costs to prepare cost comparisons for Verification Testing purposes.

Operation and maintenance (O & M) costs realized in the equipment Verification Test may be utilized for calculating cost estimates. O & M costs for each system will be determined during the equipment Verification Tests. The O & M costs that will be recorded and compared during the Verification Test include:

- Labor;

- Electricity;

- Chemical Dosage, and

- Equipment Replacement Frequency.

The capital and O & M costs will vary based on geographic location.

O & M costs should be provided for each membrane process that is tested. In order to receive the full benefit of the equipment Verification Test Programs, these costs should be considered along with quality of system operations. Other cost considerations may be added to the cost tables presented in this section as is needed prior to the start-up of the Verification Tests. A summary of O & M costs are outlined in Table 16.2.

Table 16.1: Design Parameters for Cost Analysis

Design Parameter	Specific Utility Values
Raw water feed rate(mgd)	
Total required plant production rate(mgd)	
By-pass flow rate (mgd)	
Required membrane train capacity (mgd)	
High/Low plant feedwater temperature (°C)	
Average Flux (gsfd/psi)	
Maximum Flux (gsfd/psi)	
Average cleaning frequency (days)	
High/Low feed TDS (mg/L)	

Table 16.2: Operations and Maintenance Cost

Cost Parameter	Specific Values	
Labor rate + fringe ($/personnel-hour)		
Labor overhead factor (% of labor)		
Number of O&M personnel hours per week		
Power Consumption (kWh/Million Gallons)		
Electric rate ($/kWh)		
Cost of Membrane ($)		
Membrane replacement frequency (%/year)		
Cost of Chemicals ($)		
Chemical Dosage (per week)		
O&M cost ($/Kgal)		
Disposal Costs ($)		
	Dose	Bulk Chemical Cost
Chlorine (Disinfectant)		
Sulfuric acid (Pretreatment)		
Alum (Pretreatment)		
Hydrochloric acid (Pretreatment)		
Scale inhibitor [2](Pretreatment)		
Caustic (Post-treatment)		
Sodium hydroxide (Membrane cleaning)		
Phosphoric acid (Membrane cleaning)		

[1]Information for cleaning chemicals and pretreatment chemicals (such as alum) should also be provided in this table. For cleaning agents, the concentration of the cleaning solution used to clean the membranes should be reported as the chemical dosed.

[2]Report the product name and manufacturer of the specific scale inhibitor used.

17.0 SUGGESTED READING

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